

About AP-GPFA_Phase1UtilizationTask4DataUpload Tier 2 Submission

DE-EE0006726, Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin

Abstract: This document describes the contents of a zipped folder submitted to the Geothermal Data Repository (GDR) node of the National Geothermal Data System (NGDS) in support of Phase 1 Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin. The submission includes data pertinent to the methods and results of an analysis of the Surface Levelized Cost of Heat (SLCOH) for US Census Bureau 'Places' within the study area. This was calculated using a modification of a program called GEOPHIRES, available at <http://koenraadbeckers.net/geophires/index.php>. The MATLAB modules used in conjunction with GEOPHIRES, the MATLAB data input file, the GEOPHIRES output data file, and an explanation of the software components have been provided. Results of the SLCOH analysis appear on 4 .png image files as mapped 'risk' of heat utilization. For each of the 4 image (.png) files, there is an accompanying georeferenced TIF (.tif) file by the same name.

In addition to calculating SLCOH, this Task 4 also identified many sites that may be prospects for use of a geothermal district heating system, based on their size and industry, rather than on the SLCOH. An industry sorted listing of the sites (.xlsx) and a map of these sites plotted as a layer onto different iterations of maps combining the three geological risk factors (Thermal Quality, Natural Reservoir Quality, and Risk of Seismicity) has been provided. In addition to the 6 image (.png) files of the maps in this series, a shape (.shp) file and 7 associated files are included as well.

Finally, supporting files (.pdf) describing the utilization analysis methodology and summarizing the anticipated permitting for a deep district heating system are supplied.

Key Words: Appalachian Basin, West Virginia, New York, Pennsylvania, district heating, low-temperature geothermal, Geophires, Surface Levelized Cost of Heat, SLCOH, LCOH, Demand, Heat Utilization

Citation: When referencing this dataset, please use the following:

Title: GPFA-AB_Phase1UtilizationTask4DataUpload

Dataset Authors: Kelydra Welcker (WVU), Maria Richards (SMU), Zach Frone (SMU), Calvin Whealton (Cornell), Jared Smith (Cornell) and Cathy Chickering Pace.

Note: The MATLAB modules within this submission are modifications to previous work by Tim Reber, Lizeta Gkogka, and Konstantinos Vilaetis while at Cornell University.

Date: October 2015

Corresponding Author: Maria Richards, SMU, mrichard@smu.edu.

This data submission is supplemental information to the Final Report for Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin (Project DE-EE0006726), submitted on October 16, 2015.

AP-GPFA_Phase1UtilizationTask4DataUpload includes 42 files, organized as follows:

1. This explanatory file, **About_GPFA-AB_Phase1UtilizationTask4DataUpload.pdf**.
2. **GPFA-AB_Phase1UtilizationAnalysisMemo.pdf**, describing the methodology for Utilization Analysis and in particular, the calculation of Surface Levelized Cost of Heat (SLCOH).
3. GPFA-AB_Phase1UtilizationTask4Calc_SLCOH Folder containing 15 files:
 - a. A document (.pdf) describing the software components for SLCOH calculation, **ABOUTGPFA-AB_Phase1UtilizationTask4Calc_SLCOH.pdf**
 - b. **6 MATLAB modules (.m)** used to interface to GEOPHIRES for calculation of LCOH and/or SLCOH for many Census Bureau 'places'.
 - i. **GPFA-AB_Phase1UtilizationTask4MAIN_PROGRAM.m**
 - ii. **DemandFcn.m**
 - iii. **makeInputFile.m**
 - iv. **distcostFcn.m**
 - v. **flowcalc.m**
 - vi. **functionLG.m**
 - c. **6 document files (.pdf) of the 6 MATLAB modules (.m)** used to interface to GEOPHIRES for calculation of LCOH and/or SLCOH for many Census Bureau 'places'.
 - i. **GPFA-AB_Phase1UtilizationTask4MAIN_PROGRAM.m.pdf**
 - ii. **DemandFcn.m.pdf**
 - iii. **makeInputFile.m.pdf**
 - iv. **distcostFcn.m.pdf**
 - v. **flowcalc.m.pdf**
 - vi. **functionLG.m.pdf**
 - d. The MATLAB input data, **INPUT_TABLE_STATIC_NY_PA_WV_corrected.xlsx**
 - e. The GEOPHIRES output data with additional analysis, **GPFA-AB_Phase1UtilizationSurfaceLCOH_GEOPHIRES_output.xlsx**
4. GPFA-AB_Phase1UtilizationRiskFactorMapsSLCOH Folder containing 9 files:
 - a. Four image (.png) files of the Utilization Risk Factor Maps. Variations include two different color scales of favorability (3 thresholds indicated by 3_0_3 and 5 thresholds indicated by 5_0_5), each shown with a 5 km buffer (ut5*) and without a buffer (ut0*).
 - i. **ut0_3_0_3_NA.png**
 - ii. **ut5_3_0_3_NA.png**
 - iii. **ut5_5_0_5_NA.png**
 - iv. **ut0_5_0_5_NA.png**
 - b. Four raster (.tif) files associated with the four image (.png) files of the Utilization Risk Factor Maps, and an associated file.
 - i. **ut0_3_0_3_NA.tif**
 - ii. **ut0_5_0_5_NA.tif**

- iii. **ut5_3_0_3_NA.tif**
- iv. **ut5_5_0_5_NA.tif**
- v. **ut5_5_0_5_NA.tif.aux.xml**

5. ExampleSitesByIndustryMapsAndShape Folder containing 15 files:
 - a. A workbook (.xlsx) file of prospective sites for a district heating system, sorted by industry. These were selected based on their use case profile, rather than on their SLCOH value. File is **GPFA-AB_Phase1ExampleSitesByIndustryList.xlsx**.
 - b. Six image (.png) files of the combined geologic risk factors (thermal, reservoirs, and seismic – without utilization) with the example prospective sites shown as a map layer. The combined geologic risk factors are shown using sum (s_geo) combination, product (p_geo) combination, and minimum (m_geo) combination methods. These combination methods are discussed more fully within the GPFA-AB_Phase1RiskAnalysisTask5DataUpload. Both three-color and five-color scale for all three methods are included.
 - i. **co_3_0_3_m_geo_industries.png**
 - ii. **co_3_0_9_s_geo_industries.png**
 - iii. **co_3_0_27_p_geo_industries.png**
 - iv. **co_5_0_5_m_geo_industries.png**
 - v. **co_5_0_15_s_geo_industries.png**
 - vi. **co_5_0_125_p_geo_industries.png**
 - c. A shapefile (.shp) and seven associated files (.cpg, .dbf, .lyr, .prj, .sbn, .sbx, .shx) for the six image files are provided.
 - i. **Industries_FINAL.shp**
 - ii. **Industries_FINAL.cpg**
 - iii. **Industries_FINAL.dbf**
 - iv. **Industries_FINAL.lyr**
 - v. **Industries_FINAL.prj**
 - vi. **Industries_FINAL.sbn**
 - vii. **Industries_FINAL.sbx**
 - viii. **Industries_FINAL.shx**

6. **GPFA-AB_Phase1UtilizationMemo_PermittingSummaryNY_PA_WV.pdf**, containing a preliminary summary of the anticipated permitting requirements for a deep district heating system in New York, Pennsylvania, or West Virginia.

Sources: Primary sources of information referenced in preparation of this submission include:

Beckers, K. F. (2015). *GEOPHIRES Software Tool*. Retrieved from GEOthermal Energy for the Production of Heat and Electricity Economically Simulated: <http://koenraadbeckers.net/geophires/index.php>

- Beckers, K. F., Lukawski, M. Z., Anderson, B. J., Moore, M. C., & Tester, J. W. (2014). Levelized costs of electricity and direct-use heat from Enhanced Geothermal Systems. *Journal of Renewable and Sustainable Energy, Vol. 6, No. 1*, 013141.
- Beckers, K. F., Lukawski, M. Z., Reber, T. J., Anderson, B. J., Moore, M. C., & Tester, J. W. (2013). Introducing GEOPHIRES V1.0: Software Package For Estimating Levelized Cost of Electricity and/or Heat from Enhanced Geothermal Systems. *Proceedings, Thirty-Eighth Workshop on Geothermal Reservoir Engineering*. Stanford: Stanford University. Retrieved from <http://www.geothermal-energy.org/pdf/IGAstandard/SGW/2013/Beckers.pdf>
- He, X. (2015). *Feasibility and Supply Analysis of U.S. Geothermal District Heating and Cooling Systems*. West Virginia University, Benjamin M. Statler College of Engineering and Mineral Resources. Morgantown: Proquest LLC, UMI Dissertation Publishing. Retrieved from <http://search.proquest.com/docview/1682034532>. Abstract Available at <http://gradworks.umi.com/37/01/3701975.html>
- Reber, T. J. (2013). *Evaluating Opportunities For Enhanced Geothermal System-Based District Heating In New York And Pennsylvania*. Master's Thesis, Cornell University. Retrieved from <http://hdl.handle.net/1813/34090> (restricted until 2018)
- Reber, T. J., Beckers, K. F., & Tester, J. W. (2014). The transformative potential of geothermal heating in the U.S. Energy market: a regional study of New York and Pennsylvania. *Energy Policy, Vol. 70*, 30-44.
- U.S. Census Bureau. (2000, Created 2003, Last Revised 2004, Accessed 2015). *U.S. Census Bureau*. Retrieved from Survey of Program Dynamics, Sampling Errors: <http://www.census.gov/spd/sampling.html>
- U.S. Census Bureau. (2010). *2010 census population & housing unit counts – Blocks*. Retrieved from <https://www.census.gov/geo/maps-data/data/tiger-data.html>
- U.S. Census Bureau. (2015). *U.S. Census Bureau*. Retrieved from State Quick Facts: <http://quickfacts.census.gov/qfd/states/>

Special Use Considerations:

MATLAB and GEOPHIRES are required for use of the six “.m” files:

- **GPFA-AB_Phase1UtilizationTask4MAIN_PROGRAM.m**
- **DemandFcn.m**
- **makeInputFile.m**
- **distcostFcn.m**
- **flowcalc.m**
- **functionLG.m**

GEOPHIRES (**Console1.exe**) is not included in the upload, but may be obtained from <http://koenraadbeckers.net/geophires/index.php>.

Microsoft Excel is required to view the input and output workbook files, as well as list the list of prospective sites by industry:

- **INPUT_TABLE_STATIC_NY_PA_WV_corrected.xlsx**
- **GPFA-AB_Phase1UtilizationSurfaceLCOH_GEOPHIRES_output.xlsx**
- **GPFA-AB_Phase1ExampleSitesByIndustryList.xlsx**

Methods of Calculations and Assumptions:

The Surface Levelized Cost of Heat Calculation methodology and key references may be found within files **GPFA-AB_Phase1UtilizationAnalysisMemo.pdf** and **ABOUTGPFA-AB_Phase1UtilizationTask4Calc_SLCOH.pdf**.

As described more fully within the **GPFA-AB_Phase1RiskAnalysisTask5DataUpload**, the combined risk maps were calculated using R version 2.15.1 (2012-06-22, “Roasted Marshmallows”, The R Foundation for Statistical Computing) and packages `sp`, `raster`, `rgdal`, `rasterVis`, `maps`, `maptools`, `xlsx`, `rgeos`, `RColorBrewer`, and `pracma`.

Acknowledgement: The information, data, or work presented herein was funded in part by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award Number DE- DE-EE0006726.

Disclaimer: The information, data, or work presented herein was funded in part by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.